LCA Case Studies

A Comparison of Municipal Wastewater Treatment Plants for Big Centres of Population in Galicia (Spain)

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Abstract

Background, Aims and Scope. It is clear that a wastewater treatment plant brings about an enhanced quality of wastewater; however, it also implies such environmental side effects as material and energy consumption as well as involving the generation of waste. This study is maintained within the boundaries of a research project that aims at the evaluation, from an environmental perspective, of the most common technical options focused on the removal of the organic matter present in urban wastewater. In particular, the paper presents the results for four centres of population with more than 50,000 inhabitants. The differences present among the facilities on their configurations will allow their comparison and the definition of the less environmentally damaging scheme for the treatment of this type of wastewater.

Methods. As done before, LCA was the tool used for the evaluation of the environmental performance of the systems under study. In particular, the Centre of Environmental Science (CML) of Leiden University methodology was considered.
The collection and transportation of wastewater across the pipeline was considered to be unaffected by the operation of the WTP and therefore, these stages were excluded. Within the boundaries of the treatment plants, the analysis was limited to the operation stage and no considerations were given to the building phase.
Average annual data from several years were provided to obtain the inventory data, avoiding extraordinary conditions such as flooding or prolonged stop of units.
CML factors (updated in 2002) were chosen for the impact assessment stage. SimaPro 5.1 software was used to make the calculations easier and to provide the data for the background systems.

Results and Discussion. The comparison performed showed that the different configurations entail variations on the impact categories under study. Although higher electricity consumption was reported for those facilities with secondary treatment, its implementation is recommended as better results are obtained for eutrophication, undoubtedly an important criteria when wastewater treatment systems are analysed. In particular, the discharge of ammonium and phosphorous was identified as the main contributor within this impact category. The digestion of the sludge entails several benefits as the sludge is partially stabilised, its volume significantly reduced and the impacts associated to its application to soil are minor. Concerning the several dewatering systems compared, the use of different chemicals to facilitate the water removal turned to have an influence on the environmental performance so attention to this should be paid in addition to the energy consumption associated.

Conclusions and Recommendations. Four WWTPs of capacity ranging from 75,000 to 125,000 inhabitants were evaluated in order to get more knowledge of their environmental performance. Data on material and energy consumption as well as characterisation of the water and the sludge entering and leaving the facilities were collected from the facilities in order to build the inventory required to perform the environmental assessment.
The comparison performed among the four facilities made possible the definition of a less environmentally damaging WWTP, where secondary treatment at the water line as well as filter band and anaerobic digestion at the sludge line should be included.
As mentioned, this study is part of a research project in which twenty treatment plants (divided in groups according to their capacity of treatment) are being evaluating. At the present time only results from the study of those from the highest populated areas were considered. On-going research is focused on the analysis of the plants representative for less populated areas.

Keywords: Comparative LCA; municipal wastewater treatment plant; Spain; wastewater

Introduction

The Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (also known as The European Water Act) establishes restrictive threshold concentrations in the wastewater emissions and its implementation is leading to a rapid multiplication of wastewater treatment plants (abbreviated WWTPs) across Europe.

This activity causes an enhanced environmental quality of the wastewaters; however, it also implies such side effects as material and energy consumption as well as generation of waste. Consequently, it should be analysed under the perspective of Life Cycle Assessment (LCA) methodology in order to evaluate its global environmental performance.

To the best of our knowledge, the first reference on the application of LCA to wastewater treatment dates from 1997 (Roeleveld et al. 1997), where LCA was used to evaluate the sustainability of the treatment of municipal wastewater in The Netherlands. Since then, the application of LCA to wastewater treatment has been located mainly in Sweden, where several papers (Tillman et al. 1998, Lundin et al. 2000)

have made use of this environmental management tool to evaluate and compare different scenarios for wastewater treatment in specific locations. Also under Swedish conditions, Kärrman and Jönsson (2001) presented a method to normalise the environmental impact of four wastewater systems quantifying their contribution to the total impact from their society. In Switzerland, and as a result of the Ecoinvent database project (Frischknecht et al. 2005), an Excel calculation tool was created to inventory different types of wastewater treatments assuming average Swiss technology and including the transport in sewers, the treatment in WWTP as well as the digestion and disposal of the associated sludge (Doka 2003). Going a bit further, a recent study by Lassaux et al. (2006) has analysed the whole anthropogenic water cycle, from the pumping station to the WWTP, using the Walloon Region in Belgium as case study. In Spain, this research area is less developed and, to the best of our knowledge, few references are available: on the one hand, Vidal et al. (2002) compared three configurations of biological treatment by means of simulated data instead of real information, and on the other hand, Hospido et al. (2004, 2005) provided more detailed information in the evaluation of the environmental performance of a specific municipal wastewater treatment plant and the sewage sludge generated there.

This study is maintained within the boundaries of a research project that aims at the evaluation, from an environmental perspective, of the most common technical options focused on the removal of the organic matter present in urban wastewater. Within this project, more than 20 WWTPs are under study, sorted in four groups according to their capacity of treatment: less than 5,000 inhabitants (Group 1), between 5,000 and 10,000 inhabitants (Group 2), between 10,000 and 50,000 inhabitants (Group 3) and more than 50,000 inhabitants (Group 4).

In particular, Group 4 comprises four WWTPs corresponding to four of the seven centres of population of more than 50,000 inhabitants in Galicia (Spain). According to the National Institute of Statistics (INE 2004), 35.45% of the Galician populations live in these cities, a percentage which is a bit distant from the national average (50.63%).

To perform the study, the development of a reliable inventory of each WWTP was required: an extensive analysis of all the input and output flows is deemed to be presented in tables with average values representative of a one-year period. Afterwards, the impact assessment stage allows the evaluation of the environmental performance of typical configurations for WWTPs as well as the identification of the main environmental loads and their origins.

1 Goal and Scope Definition

1.1 Objectives

The general goal of this study is the environmental evaluation of the most common technical options for urban wastewater. In particular, our interest is focused on the description of the environmental performance of their typical working conditions by identifying the main contributors to the global environmental impact of the facilities for a particular group as well as the comparison of several current units among the possible configurations for water and sludge line of treatment.

1.2 Functional unit

The main purpose of any WWTP is the removal of pollutants from the wastewater and, consequently, the reduction of emissions (mainly solids, organic matter and nutrients) when the treated effluent is discharged to natural watercourses.

Regarding the definition of the functional unit, several options may be taken into account such as the quantity of removed pollutants or the volume of the treated wastewater or the generated sludge. According to the recommendations of Suh and Rousseaux (2001), the quantity of inflow water in a certain period of time appears to be the best choice since it is based on realistic data. However, the treatment of the wastewater generated from one person equivalent (pe) was established here as this parameter assists the comparison among different WWTPs (Tillman et al. 1998).

1.3 System boundaries

The different LCA studies accomplished on urban water systems established diverse choices for system boundaries (Lundin et al. 2000). Bearing in mind the purpose of the study, the system boundaries were defined here as described below.

According to Doka (2003) and Lassaux et al. (2006), the sewer system, mainly due to its construction, accounts for a non-negligible environmental load. However, the study presented here aims for the comparison of different technical options at the plant level and, as a result, the collection and transportation of wastewater across the pipeline is not affected by the operation of the WWTP. Therefore, these stages can be excluded and the initial point of this study is the chamber receiving the wastewater at the WWTP.

Within the boundaries of the treatment plant, both Lundie et al. (2004) and Lassaux et al. (2006) have reported that the impact of the operation phase is larger than that of the construction stage. In addition, Tillman et al. (1998) found that the investment impacts were similar for their different alternatives in contrast to those related to the operation of the treatment systems. Bearing all these in mind, the analysis presented here was limited to the operation stage of the WWTP and no considerations were given to the building phase.

So, the focus of this comparison is the WWTP operation, a stage that has been reported by Lassaux et al. (2006) as one of the three main contributors to the global environmental load along the whole anthropogenic water cycle.

A typical WWTP has three different lines: water, sludge and biogas (optional). Although the units can vary among facilities, a general system comprising five subsystems was defined for the four WWTPs, including not only the treatment of the influent but also the different solid fractions and sludge generated as well as the production of electricity, the manufacture of chemicals and their transportation by road. A short

Table 1: Configuration and capacity (stated as person equivalents) of the facilities under study

Subsystem		WWTP 1 ≈ 125,000 pe	WWTP 2 ≈ 110,000 pe	WWTP 3 ≈ 107,000 pe	WWTP 4 ≈ 72,000 pe
1	Input of raw water	✓	✓	✓	✓
	Pre-treatment	✓	✓	✓	✓
	Primary treatment	✓	✓	✓	✓
	Discharge of partially treated water into the watercourse	✓	-	✓	✓
	Transportation and treatment of the solid fractions generated	✓	✓	✓	✓
2	Secondary treatment (activated sludge)	✓	✓	✓	-
	Discharge of treated water into the watercourse	✓	✓	✓	✓
3	Thickening of sludge	✓	✓	✓	✓
	Anaerobic digestion of sludge	✓	–	✓	✓
	Production and internal use of biogas	✓	–	✓	✓
	Dewatering of digested sludge with centrifuges	–	–	✓	–
	Dewatering of digested sludge with filter press	–	✓	–	–
	Dewatering of digested sludge with filter band	✓	–	-	✓
	Production and transport of chemical reagents for dewatering	✓	✓	✓	✓
4	Consumption of electricity that cannot be allocated to other subsystems, such as auxiliary services and general illumination	✓	✓	✓	✓
	Production and transport of chemical reagents for deodorisation towers	–	–	✓	✓
5	Storage of filter cake	✓	✓	✓	✓
	Transport of treated sludge to farms	✓	✓	✓	✓
	Application to land for agricultural purpose	✓	✓	✓	✓

description of the specific configuration of every subsystem at each WWTP is presented in **Table 1**.

1.4 Data quality and simplifications

The company in charge of the wastewater management provided average annual data from several years, avoiding such extraordinary conditions as flooding or prolonged stop of units. As a result, the years used to define the typical year of operation were: 2002–2003 for WWTP1, 1998–2003 for WWTP2, 2002–2003 for WWTP3 and 2000–2003 for WWTP4.

In addition, some complementary data were obtained from SimaPro databases, which are described next:

- Electricity. Due to the non-availability of accurate data on electricity consumption per subsystem, an electrical energy distribution across the process was estimated considering the theoretical power requirement of each unit as well as the computed working hours. In relation to the electricity production profile, data from the Institute for Diversification and Saving of Energy was used (IDAE 2004). Although, some data for the environmental burdens of electricity production in Spain have been recently derived from a major EU funded research project called ExternE (2004), their high uncertainty only allows their use as background information. Consequently, information from a well-known database, IDEMAT (2001), was selected.
- Generation, transport and treatment of solid waste. The accurate quantification of the amount of each faction of solid waste generated (grease waste, inert residue and municipal solid waste) was not viable, therefore their productions were estimated by means of the volume and frequency of each collection truck. The specific waste treatment was different according to the residue characteristics: inertisation for grease wastes and landfills both for inert residues as well as for municipal solid waste.
- Polymeric flocculants (polyacrylamides) are added for sludge conditioning and dewatering. As no information was available for polyacrylamide production, data regarding acrylonitrile fabrication (IDEMAT 2001), one of the key raw materials used in acrylamide manufacture (Ullmann 1997), were used in the analysis.
- CO_2 emissions from the aeration tank as well as from the combustion of biogas were not taken into account as CO_2 generation is biogenic (it belongs to the short CO_2-cycle) and, consequently, it does not contribute to the climatic change.
- Methane emissions (if conditions for anaerobic degradation take place) and nitrogen compounds - nitrous oxide and ammonia - derived from the application of sludge on agricultural land were estimated by means of emission factors from the literature (Hobson 2003 and Lundin et al. 2000).
- Fertilisers avoided: Phosphorous and nitrogen are inorganic macronutrients, both of which are essential for all living organisms. Sewage sludge contains both elements in an important percentage that transforms this waste into a beneficial material prone to be recycled. Therefore, assuming the agricultural production to be constant, land application of sewage sludge reduces the need for other types of fertiliser. The substitutability was assumed to be 70% for phosphorus and 50% for nitrogen (Bengtsson et al. 1997). Concerning industrial products to be avoided, N-based and P-based fertilisers were chosen (IDEMAT 2001).

2 Operational Conditions at the Four WWTPs

A short description of the four facilities was presented in Table 1 and a summary of the data handled for the comparison is now displayed in **Table 2**. As clearly derived from the figures, the particular configuration of each plant affects the related values that described its steady performance.

The main differences among the WWTPs can be detailed as follows:

- Water line: Presence or absence of secondary treatment
- Sludge line: Presence or absence of anaerobic digestion as well as implementation of different types of units for sludge dewatering
- Ancillary activities: Presence or absence of deodorisation towers for odour treatment

Table 2: Relevant parameters of the inventory data for the WWTPs. All data are presented per person equivalent (pe)

	WWTP 1	WWTP 2	WWTP 3	WWTP 4
Inputs from Background System				
Electricity (kWh)	19.6	28.6	36.6	13.2
Polymer (g)	41	– [a]	91	10
Outputs for Further Treatment				
Solid waste (kg) [b]	8.54	0.98	7.97	8.66
Avoided Products				
N as Fertiliser (g)	341	965	360	84
P as Fertiliser (g)	195	335	84	21
Emissions to Water				
Total COD (kg) [c]	18.6	5.7	18.9	32.9
Total BOD (kg) [d]	7.29	1.92	8.60	10.5
Total N (kg) [e]	2.71	2.40	2.58	6.33
Total P (g)	77	113	622	333
Cr (g)	N.D.	N.D.	N.D.	31
Cu (g)	3.8	3.8	23.4	6.0
Fe (g)	N.D.	20	109	636
Pb (g)	N.D.	N.D.	N.D.	108
Zn (g)	20	16	54	N.D.
Emissions to Soil				
Sludge (kg) [f]	9.48	44.8	8.57	2.46
Cd (mg)	13	241	5.8	7.9
Cr (mg)	745	4,469	425	123
Cu (mg)	1,819	9,454	3,466	583
Hg (mg)	14	27	30	11
Ni (mg)	275	2,461	208	54
Pb (mg)	3,145	3,375	941	606
Zn (mg)	14,324	19,279	4,846	1,659
Emissions to Air				
CH_4 (g)	47	897	43	12
N_2O (g)	5.4	15	5.6	1.3
NH_3 (g)	104	293	109	25

N.D. = not detectable
[a] The dewatering system used at WWTP2 requires different chemicals to achieve a certain degree of dryness in the final sludge; in particular, iron chloride and lime are consumed instead of polymer
[b] Including several types of waste: inert waste, municipal solid waste and fatty waste
[c] COD = Chemical Organic Demand
[d] BOD = Biological Organic Demand
[e] Including different N-forms, such as ammonium, nitrate and nitrite
[f] Stated as grams of dry matter

3 Environmental impact caused by the WWTPs

Fig. 1 shows the indicator results from the characterisation phase at the life cycle impact assessment. To do so, the characterisation factors reported by the Centre of Environmental Science of Leiden University (CML 2 2002 according to the SimaPro 5.1 nomenclature) were used. In addition, and in order to make the chart clearer, values were indexed using the WWTP1 as baseline (Index = 100 for each impact category).

3.1 Eutrophication (EU)

Eutrophication was defined by Hellström et al. (2000) as one of the priority criteria for the definition of sustainable wastewater treatments. Not surprisingly, the discharge to the watercourse of treated or partially treated effluents (subsystems 1 and 2) totally regulates the impact on eutrophication.

At WWTP 4, the non-existence of secondary treatment leads to the discharge of wastewater presenting a significant pollution and, as a result, producing a great impact on the environment (see Fig. 1). At WWTP 1 and 3, around one half of

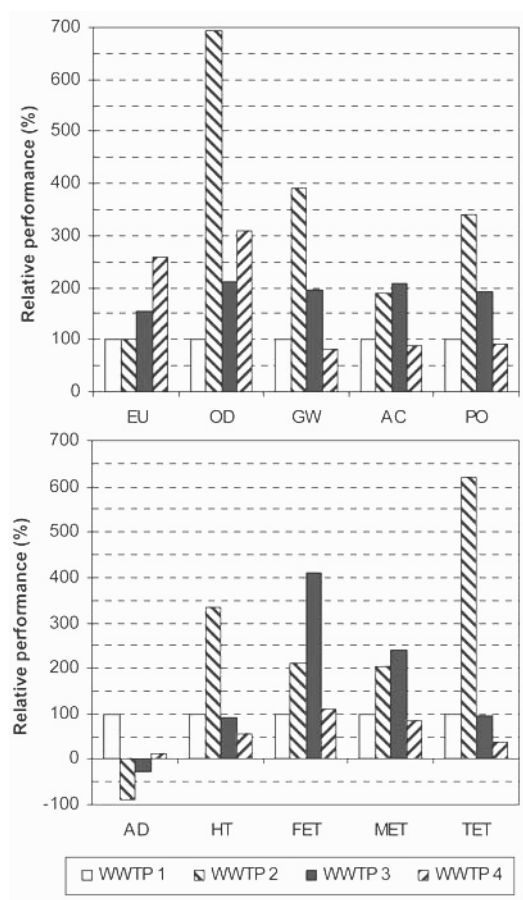

Fig. 1: Relative environmental profile of the compared scenarios, with WWTP1 being the baseline (Index = 100). Impact category acronyms: EU = Eutrophication, OD = Ozone Depletion, GW = Global Warming, AC = Acidification, PO = Photo-Oxidants formation, AD = Abiotic Depletion, HT = Human Toxicity, FET = Freshwater aquatic EcoToxicity, MET = Marine aquatic EcoToxicity and TET = Terrestrial EcoToxicity

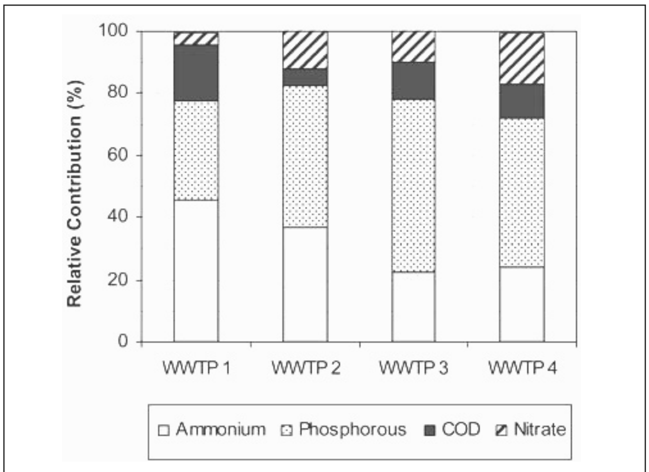

Fig. 2: Contribution analysis of the main substance involved in eutrophication

the flow crosses both primary and secondary treatment (subsystem 2), but the other half only goes through the primary one (subsystem 1). The WWTP 2 is the only one capable of processing all the water entering the plant; however, it should be mentioned that a by-pass for exceeding input flow occurs before the WWTP gate and was not included in the analysis due to the lack of information.

A further analysis was performed so as to identify the specific substances behind these environmental impacts (**Fig. 2**). As a result, two substances were found to account for more than 70% of the total value of the impact category: ammonium and phosphorous.

The improvement actions proposed can be fixed on two specific directions, related to the topics previously mentioned:

- An accurate over-dimension of the treatment plant is desirable considering both the amount of pluvial waters and the expected growth of the urban and industrial surrounding areas. This aspect will avoid the discharge of partially treated flows, which entails important contributions to the eutrophication of watercourses (almost 60% at WWTP1 and around 55% at WWTP3).
- The need for considering nitrogen and/or phosphate removal in the design of WWTPs. In fact, this action was proposed by several authors as the proper way to face eutrophication impact either by means of the adaptation of the current system or by means of a redefinition of the treatment system. Vidal et al. (2002) considered the first option with two possible configurations (Ludzack-Ettiger and oxidation ditch) for nitrogen elimination, which were compared with a reference scenario (activated sludge). Related to the second approach, Tillman et al. (1998) as well as Lundin et al. (2000) have emphasised the environmental advantages of separation systems in opposition to conventional systems (as are all the WWTP here under study) and, in particular, they have pointed out urine separation as a very effective means of dealing with both organic matter and nitrogen, improving the opportunities for recycling and avoiding their direct release to the environment.

3.2 Ozone depletion (OD)

The differences on the dewatering system at WWTP2 (subsystem 3) are behind the high value for this impact category. In fact, the production of the chemicals involved (lime and iron chloride) represents almost half of the total ozone depletion associated with this facility. The same compounds, although to a lesser degree, are used also at WWTP4 (subsystem 1) and its manufacture is responsible for the significant value of OD at this plant.

When those chemicals were excluded, OD is totally dependent of electricity production (see below).

3.3 Global warming (GW)

Kärrman and Jönsson (2001) reported that 12 kg of CO_2 equivalents are emitted per pe and year when using a conventional system for wastewater treatment. Here, two of the four facilities are in agreement with this figure (13.8 and 11.1 kg of CO_2 equivalents per pe at WWTP1 and WWTP4, respectively, being higher than the values for WWTP2 and WWTP3).

A detailed analysis was carried to identify the subsystems that contribute most to the global warming impact (**Table 3**) and it was found that all of them were involved to similar extend in the generation of gases that aggravate the global warming. In particular, two are the substances that contribute most: CO_2 emissions in electricity production and CH_4 emissions when sludge is applied on agricultural soil.

The second source in particular was estimated by means of emission factors taken from the available literature as no real information was accessible. The production of methane is related to the anaerobic decomposition of the sewage sludge in the soil, which may occur in wet climate where the soils are waterlogged during an important fraction of the year (Hobson 2003). Taking into account the characteristics of the Galician climate, the anaerobic degradation of the sludge applied to soil was considered and CH_4 emissions estimated and included in the inventory. However, that inclusion can be considered very general as aspects such as the capacity of the soils for drainage may influence and, consequently, a sensitivity analysis to evaluate the effect of considering anaerobic versus aerobic degradation of the sludge in the soil is interesting (**Fig. 3**). As can be observed, only the value for WWTP2 is affected as it involves the greater amount of sludge as well as the higher emission factor (for not digested sludge). Nevertheless, even under aerobic conditions, WWTP2 presents the higher value for GW with more than 30 kg of CO_2 equivalents per pe. If CH_4 emissions are not regarded, GW is mainly regulated by the CO_2 emissions from electricity consumption that is analysed below.

Table 3: Analysis of contribution per subsystem for the Global Warming. All data are presented as %

	WWTP 1	WWTP 2	WWTP 3	WWTP 4
Subsystem 1	35.33	11.40	33.98	72.88
Subsystem 2	34.78	16.26	38.76	–
Subsystem 3	10.72	22.85	12.55	18.95
Subsystem 4	2.19	1.83	3.73	1.87
Subsystem 5	16.99	47.66	10.98	6.30

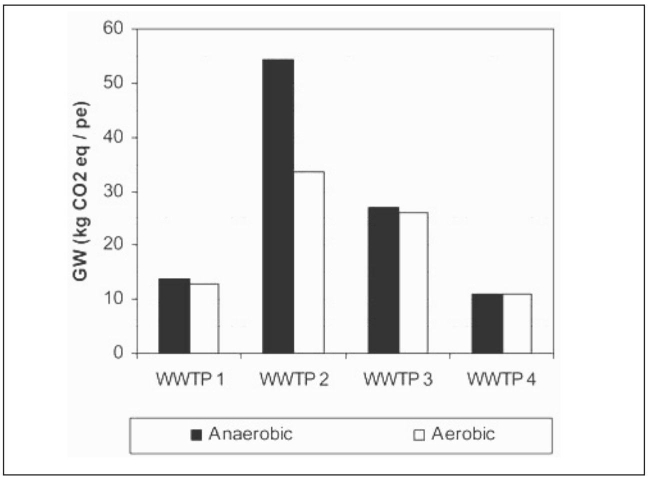

Fig. 3: Influence of CH_4 emission factors associated with the conditions of sludge degradation in soils associated with Global Warming

3.4 Acidification (AC)

Emissions triggering acidification are mainly caused at electricity production and, therefore, this parameter constrains AC (subsystems 1, 2 and 3 in Table 3). From smaller to higher consumption: 13.2 kWh/pe (WWTP 4), 19.6 kWh/pe (WWTP 1), 28.6 kWh/pe (WWTP 2) and 36.6 kWh/pe (WWTP 3), these values are in agreement with those available in literature: similar to the 33 kWh/pe reported by Lundin et al. 2000 and slightly inferior to the 46.4 kWh/pe reported by Tillman et al. 1998, likely due to a factor scale as the plant analysed there had a capacity of 20,000 inhabitants. In addition and bearing in mind that WWTP 4 should be excluded from this statement as it lacks secondary treatment, it can be confirmed that the higher amount of water, the lower consumption of electricity per person equivalent is derived.

3.5 Photo-oxidants formation (PO)

Among the impact categories typically considered by LCA studies, Lundie et al. (2004) listed PO as one of the categories of relevance to the water industry. According to Kärrman and Jönsson (2001), 100 g of ethane equivalents are emitted per pe when using a conventional system for wastewater treatment. The values reported here are far smaller, being the higher (WWTP2) 12 g per pe, than those, as a result of a less significant energy use (direct and indirect), element that dominates the emissions associated with this impact category.

3.6 Abiotic resources depletion (AD)

The production of chemicals and the avoided manufacture of fertilisers balance the negative and positive effects of the WWTP of this impact category. In particular, the stabilisation of the fatty waste that takes place only at WWTP1 dominates this impact category due to the production of the cement that is consumed there. If this process is disregarded, the comparison is dominated by the avoided burdens associated with the use of sludge as fertiliser.

3.7 Toxicological categories (HT, FET, MET and TET)

Although the characterisation models for the definition of toxicological impact categories are still looking for consensus among the LCA community (Larsen et al. 2004), they are important when dealing with water systems (Lundie et al. 2004).

In particular, and taking into account the data available regarding toxic compounds (heavy metals in the sludge), we focus the discussion on the Terrestrial Ecotoxicity category (TET). The application of sludge on agricultural land (subsystem 5) totally dominates the impact and, in this sense, it must be noticed that the most adverse case was applied, so that the numbers represent the maximum possible values. Although more research is required to accurately establish the amount of heavy metals that in fact reach the soil, some attempts have been carried with soils of the region under study (Monterroso et al. 2003); however, only values for Cr, Cu, Ni, Pb and Zn were reported there.

The amount of sludge at the WWTPs is dependent on two opposite aspects: the implementation of secondary treatment and anaerobic digestion. If the former occurs, a higher production takes place. If the latter happens, a great reduction of sludge is achieved. WWTP 2 combines both aspects in a negative direction (presence of secondary treatment and absence of anaerobic digestion) so a huge amount of sludge is produced (see Table 2) and an extremely high impact is brought about (see Fig. 1). On the contrary, WWTP 4 merges both effects in a positive sense (absence of secondary treatment and presence of anaerobic digestion), which explains the minor value attained for this impact category (see Fig. 1). In WWTP 1 and 3, both aspects are balanced (absence of secondary treatment as well as anaerobic digestion) and comparable values are obtained for the two plants.

The definition of improvement actions to tackle the important impact on terrestrial toxicology is not a simple duty. Sludge quality results from the quality of wastewater entering the WWTP; therefore, more effort should be made to ensure the quality of wastewater by enforcing stricter discharge standards for industrial wastewater (believed a priori to be responsible primarily). However, other recent reports show the complexity to identify the sources of metals which contribute to the wastewater pollution; for instance, it has been reported that only a negligible fraction, 4% or less, of the present contribution of heavy metals to WWTP in Stockholm (Sweden) is derived from large size factories; surprisingly, the contribution also seems to be rather marginal from smaller ones (Sörme and Lagerkvist 2002). In Gothenburg (also in Sweden), measurements in the early 1990s showed that the total contribution to WWTPs from small factories was 3% for the following heavy metals: Zn, Hg, Ni, Cr and Cd, 6% for Cu and 12% for Pb (Mattson et al. 1991 cited at Sörme et al. 2003). All these results suggest that there is a diffuse pollution source, which is difficult to be identified. Substance flow analysis (SFA) has been used to search for alternatives to reduce sources and conclusions regarding the opportunities for wastewater utilities to manage and to reduce sources of heavy metals are to a certain extent encouraging for only certain metals such as Ni (Lind-

qvist-Östblom et al. 2001). Consequently, WWTP cannot be regarded as a separate phenomenon in society but as a part of the system of material flows, since reducing the WWTP emissions might involve a reduction in the inflow of heavy metals in society and a better overview of the urban erosion processes in order to decrease the diffuse sources (Sörme et al. 2003).

4 Environmental Comparison According to the Different Configurations

As mentioned above, there are several differences among the plants under study. In this section, an analysis regarding how these dissimilarities affect the environmental performance of the WWTP is presented.

4.1 Secondary treatment of wastewater

At WWTP4, no more than a primary treatment is being performed for removal of pollutants from the wastewater. The average yield for organic matter removal is less than 30%, which is an indication of the poor decontamination taking place. Not surprisingly, this situation is reflected on the eutrophication category with a two-fold impact in comparison with the other WWTPs (see Fig. 1).

The secondary treatment existing in the other three plants is focused on the removal of organic matter, but not on the elimination of N and P. Although their proper performance also entails the indirect removal of those nutrients as the bacteria existing in the reactor consume them, a specific design for N removal should be an improvement action to be considered.

Bearing in mind that the main purpose of WWTP is the removal of pollutants from the water and that eutrophication turned out to be one of the most significant categories, a secondary treatment aiming for the elimination of organic matter, nitrogen and phosphorous, and designed in agreement with the required capacity of treatment to avoid by-pass of untreated water, should be included on the design of a WWTP for populations higher than 50,000 inhabitants. In fact, this suggestion totally agrees with the current tendency and should be taken into account mainly when dealing with facilities of around ten or fifteen years old, as the ones here under study, for possible adaptation or rebuilding.

4.2 Anaerobic digestion of sludge

The most evident benefit that goes together with anaerobic digestion is the reduction of the amount of sludge generated at a WWTP. Moreover, a stabilisation is achieved and, consequently, a more safe application of the sludge to the soil takes place. This factor is undoubtedly important as sludge is very often used as soil amendment in our region.

As was presented above, two impact categories are influenced totally by the existence of anaerobic digestion: terrestrial toxicology and, to lesser extent, global warming. In both cases, the presence of anaerobic digestion proved to be the right option.

Taking into consideration these ideas, it seems to be evident that anaerobic digestion should also be included on the design of a WWTP for centres of population higher than 50,000 inhabitants.

4.3 Different types of units for sludge dewatering

Three equipments for sludge dewatering were analysed: filter band at WWTP1 and WWTP4, filter press at WWTP2 and centrifuges at WWTP3. Each option entails a specific electrical consumption and the use of particular chemicals.

No direct comparison per ton of sludge was possible as specific information concerning the electrical consumption of the dewatering system was only available for WWTP1, filter band. However, some considerations can be made. The analysis of contribution per subsystems shows that subsystem 3 (where dewatering unit is included) had a higher contribution at WWTP 2, which, as mentioned, can be explained on the basis that a higher dryness is achievable at the final cake there by the expense of a more chemically-demanding system (10.8 kg of lime and 6.1 kg of iron chloride per pe, versus 41 g, 91 g and 10 g of polymer at WWTP 1, 3 and 4, respectively). In addition, and as results are presented per pe, the non-existence of digestion at WWTP2 worsens the contribution of this subsystem as a higher amount of sludge is produced and, consequently, a higher amount of chemicals are required to attain the dryness required.

4.4 Deodorisation towers for odour treatment

Although the climate of the region helps in intensifying the problems associated with odours at the WWTPs, two of the plants (WWTP 2 and 3) have two deodorisation towers where several chemicals (sulphuric acid, sodium hypochlorite and sodium hydroxide at the former and hydrogen peroxide, sodium hypochlorite and sodium hydroxide at the latter) are added to purify the gas collected. The production and transportation of those compounds stands for less that 1% of the total impact in all the impact categories studied, so its influence can be considered negligible.

However, it should be noted that no information regarding the release of neither polluted (WWTP 1 and 4) nor treated (WWTP 2 and 3) was included to the lack of analytical results on that flow.

5 Conclusions

In this paper, four WWTPs of capacity ranging from 75,000 to 125,000 inhabitants were evaluated in order to know more regarding their environmental performance. Data on material and energy consumption as well as characterisation of the water and the sludge entering and leaving the facilities were collected from the facilities in order to build the inventory required to perform the environmental assessment.

The comparison carried out has shown that the different configurations regarding the water (existence of secondary treatment) and the sludge (existence of anaerobic digestion and diverse systems for dewatering) line affects the environmental performance of the wastewater treatment plants.

Related to the former, and although a higher electricity consumption was reported for those facilities where a secondary treatment took place and consequently a higher impact in those impact categories dominates for this element, its existence is recommended as better results are obtained for eutrophication, undoubtedly an important criteria when wastewater treatment systems are analysed. Within this impact category, the discharge to the environment of untreated ammonium and phosphorous, both in the treated and in the partially treated water stream, was identified as the main contributor and, in this sense, two improvement actions to cope with this impact were proposed: the correct dimension of the facilities capacity to avoid the appearance of discharge of partially-treated flows and the consideration of nitrogen and/or phosphate removal in the design of WWTPs.

The digestion of the sludge also entails several benefits as the sludge is partially stabilised and the volume significantly reduced. In addition, biogas is produced so the recovery of the energy content is possible. Concerning the several dewatering systems compared, the use of different chemicals to facilitate the water removal turned out to have an influence on the environmental performance so attention to this should be paid in addition to the energy consumption associated.

Therefore, the comparison performed among the four facilities made possible the definition of a less environmentally damaging WWTP, where secondary treatment at the water line as well as filter band and anaerobic digestion at the sludge line should be included.

References

Bengtsson M, Lundin M, Molander S (1997): Life cycle assessment of wastewater systems: case studies of conventional treatment, urine sorting and liquid composting in three Swedish municipalities. Report 1997:9, Chalmers University of Technology, Gothenburg, Sweden

Doka G (2003): Life cycle inventories of waste treatment services: Part IV – Wastewater treatment. Ecoinvent report No. 13, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland

ExternE (2004): Externalities of Energy, A research project of the European Commission. Available at <http://www.externe.info>

Frischknecht R, Jungbluth N, Althaus H, Doka G, Dones R, Heck T, Hellweg S, Hischier R, Nemecek T, Rebitzer G, Spielmann M (2005): The Ecoinvent database: Overview and methodological framework. Int J LCA 10 (1) 3–9

Hellström D, Jeppson U, Kärrman E (2000): A framework for system analysis of sustainable urban water management. Environ Impact Assess Rev 20, 311–321

Hobson J (2003): CH_4 and N_2O emissions from waste water handling. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at <http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_2_CH4_N2O_Waste_Water.pdf>

Hospido A, Moreira MT, Fernández-Couto M, Feijoo G (2004): Environmental Performance of a Municipal Wastewater Treatment Plant. Int J LCA 9 (4) 261–271

Hospido A, Moreira MT, Martín M, Rigola M, Feijoo G (2005): Environmental Evaluation of Different Treatment Processes for Sludge from Urban Wastewater Treatments: Anaerobic Digestion versus Thermal Processes. Int J LCA 10 (5) 336–345

IDAE (2004): Instituto para la Diversificación y Ahorro de la Energía. Boletín 6: Eficiencia energética y energías renovables [In Spanish]. Available at <http://www.idae.es>

IDEMAT (2001): Inventory Data of Materials. Faculty of Design, Engineering and Production, Delft University of Technology, Delft, The Netherlands

INE (2004): Instituto Nacional de Estadística. Population and Housing Census, 2001. Available at <http://www.ine.es/inebase/menu2_dem_en.htm>

Kärrman E, Jönsson H (2001): Normalising impacts in an environmental systems analysis of wastewater systems. Wat Sci Technol 43 (5) 293–300

Larsen HF, Birkved M, Hauschild M, Pennington D, Guinée J (2204): Evaluation of Selection Methods for Toxicological Impacts in LCA – Recommendations for OMNIITOX. Int J LCA 9 (5) 307–319

Lassaux S, Renzoni R, Germanin A (2007): Life cycle assessment of water: From the pumping station to the wastewater treatment plant. Int J LCA 12 (2) 118–126

Lindqvist-Östblom A, Sörme L, Söderberg H (2001): Substance flow analysis as a tool to support environmental management of heavy metals in wastewater treatment companies. Economic growth, material flows and environmental pressure, April 2001, Stockholm, Sweden. Available at <http://www.account2001.scb.se/prog.asp>

Lundie S, Peters GM, Beavis PC (2004): Life Cycle Assessment for sustainable metropolitan water systems planning. Environ Sci Technol 38, 3465–3473

Lundin M, Bengtsson M, Molander S (2000): Life Cycle Assessment of wastewater systems: Influence of system boundaries and scale on calculated environmental loads. Environ Sci Technol 34 (1) 180–186

Mattson J, Avergård I, Robinsson P (1991): Priority pollutants, heavy metals and main constituents in the domestic sewage from two residential areas in Gothenburg. Vatten 47, 204–211

Monterroso C, Kidd P, Macias F (2003): Bioavailability of heavy metals in sewage sludge-amended soils as affected by soil parent material. 7th International Conference on the Biogeochemistry of Trace Elements, Uppsala, Sweden

Roeleveld PJ, Klapwijk A, Eggels PG, Rulkens WH, van Starkenburg W (1997): Sustainability of municipal wastewater treatment. Wat Sci & Technol 35 (10) 221–228

Sörme L, Lagerkvist R (2002): Sources of heavy metals in urban wastewater in Stockholm. Sci Tot Environ 298, 131–145

Sörme L, Lindqvist-Östblom A, Söderberg H (2003): Capacity to influence sources of heavy metals to wastewater treatment sludge. Environ Manage 31 (3) 412–428

Suh YJ, Rousseaux P (2001): Considerations in Life Cycle Inventory analysis of municipal wastewater treatment systems. Oral presentation at COST 624 WG Meeting, Bologna, Italy <http://www.ensic.inpl-nancy.fr/COSTWWTP/>

Tillman A-M, Svingby M, Lundström H (1998): Life Cycle Assessment of municipal waste water systems. Int J LCA 3 (3) 145–157

Ullmann F (1997): Ullmann's Encyclopaedia of Industrial Chemistry. Electronic Format

Vidal N, Poch M, Martí E, Rodríguez-Roda I (2002): Evaluation on the environmental implications to include structural changes in a wastewater treatment plant. J Chem Technol Biotechnol 77, 1206–1211

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